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A new phase-meter using a thyratron

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A thyratron tube which is used as a phasemeter shows a fair possibility of measuring varying phase difference between two constant voltages, although the instrument can be adapted for other measurements. An approximate analytical expression relating the average rectified current (I) and the phase difference (θ) has been obtained. The limitations of the instrument have been pointed out.

1. THEORY

Let us suppose that an alternating voltage of considerable magnitude is applied to the plate and a relatively smaller alternating voltage is applied to the grid of the thyratron.

The plate current (i) can only flow, if at all, during a fraction of the positive half-cycle of the plate voltage and it starts when the instantaneous grid voltage (e_g) goes just more positive than the critical (cut-off) value corresponding to the instantaneous plate voltage (e_p). Once started the plate current (i) is independent of the grid voltage and tends to jump to the full emission of the cathode even with a very low plate voltage of the order of 15 volts. i is however, limited by the resistance (R) in the plate circuit and remains substantially constant during the conducting period of the tube. It stops only when e_p falls below the value at which the ionisation can no longer be maintained in the tube.

To understand the dependence of I, the average rectified current, on the phase relation between the plate and grid voltages, let us suppose at first that the phase-difference (θ) between the two voltages is zero. Under this condition the grid and the plate go positive simultaneously and conduction starts almost at the start of the positive half cycle. On the other hand, if

$\theta = \pi$, the grid goes negative as the plate goes positive, and the conduction starts, if at all, rather late in the cycle. It is so because $e_p^{\cdot}$ must attain a certain magnitude before it can start the conduction overcoming the biasing effect of $e_g^{\cdot}$.

With proper adjustment of the relative magnitudes of the two voltages ($E_g > E_p/\mu$) the tube may not conduct at all. This can be done with the help of a potentiometer P_1 in the grid circuit (figure 2).

It is obvious that although the starting point ϕ of the conduction period depends on θ, the extinction point does not. Therefore, the conduction period depends on θ, being greater as θ becomes smaller. An ammeter included in the plate circuit reads I which increases with decreasing θ.

A rough estimation of I can be done by assuming i to remain substantially constant and that conduction starts only when e_g is more positive than the cut-off bias for e_p (as in the case of high-vacuum tube).

Let $e_p^{\cdot} = E_p \sin \omega t$ and $e_g = E_g \sin (\omega t - \theta)$, then $e_p^{\cdot}/\mu + e_g^{\cdot}$ must be zero for the initiation of i, where μ is the amplification factor of the tube. Then,

$$E_p \sin \omega t + \mu E_g \sin (\omega t - \theta) = 0$$

or $\sin \omega t (E_p + \mu E_g \cos \theta) - \cos \omega t (\mu E_a \sin \theta) = 0$.

Putting $E_p + \mu E_g \cos \theta = R \cos \phi$; and $\mu E_g \sin \theta = R \sin \phi$ the equation reduces to $R \sin (\omega t - \phi) = 0$ ...(1).

Therefore, either $R=0$ or $\sin (\omega t - \phi) = 0$.

where, $\phi = \tan^{-1} \dfrac{\mu E_g \sin \theta}{E_p + \mu E_g \cos \theta}$ and $R = \{E_p^2 + \mu^2 E_g^2 + 2\mu E_p E_g \cos \theta\}^{\frac{1}{2}}$

But $R=0$, only when $E_p = \mu E_g$ and $\theta = \pi, 3\pi \ldots$;

whereas, $\sin (\omega t - \phi) = 0$, when $(\omega t - \phi) = 0, \pi, 2\pi \ldots$

If E_g is adjusted with the help of P_1 so that $\mu E_g = E_p$

we get, $\phi = \tan^{-1} \tan \dfrac{\theta}{2}$ or $\phi = \dfrac{\theta}{2}$. (2)

This shows that the initiation of the current takes place when $\omega t = \phi = \theta/2$. If the extinction takes place, for the given tube, at $\omega t = \alpha$, this can be determined from the knowledge of extinction potential and E_p. Therefore I is given by

$$I = \int i dt/T = i \int_{\phi/\omega}^{\alpha/\omega} dt \Big| 2\pi/\omega = i(2\alpha - \theta)/4\pi \tag{3}$$

(provided i is constant)

The equation 3 shows that I varies linearly with θ. The maximum theoretical limit of θ are given by 2α and the minimum by 0. Actually, however, these are of theoretical interest as there is no point in measuring the phase difference which is greater than π. This will be equivalent to interchanging the leading phase into lagging phase and vice-versa.

2. Discussions

The equation 3 holds only under the condition $E_p/\mu = E_g$ and therefore, the relative magnitudes of E_p and E_g must be maintained. The plate current also depends to a small extent on the absolute value of E_p, therefore E_p should be constant. Both the voltages may be made constant with the help of suitable potential dividers.

It is, however, possible to calibrate the instrument with any particular ratio (greater than 1) of E_p to E_g and to maintain the relative and absolute values of the voltages constant thereafter.

For $\theta = \pi$, if E_g is slightly smaller than E_p/μ then the conduction will start at $\omega t = \pi/2$ and I is given by $i\ (2\alpha - \theta)/4\pi$ (equation 3).

With this value of θ, if E_g is increased and just crosses E_p/μ no conduction is possible and I reduces to zero. Under this condition equation 2 is only approximately valid and ϕ will be greater than $\theta/2$. $I-\theta$ graph is again nearly linear but equation 3 no longer represents it accurately. At $\theta = \pi$ there is sharp fall to zero. This fall is not so much due to ϕ approaching and becoming equal to α (*i.e.* smaller conduction period) but due to no conduction at all, at this relative magnitudes of E_g and E_p. The relation between $I-\theta$ is shown by graph I in figure 1.

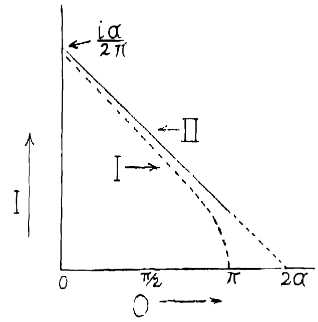

Figure 1. The graphs showing I-θ relationship.
Graph I E_g just greater than E_p/μ.
Graph II E_g just smaller than E_p/μ.

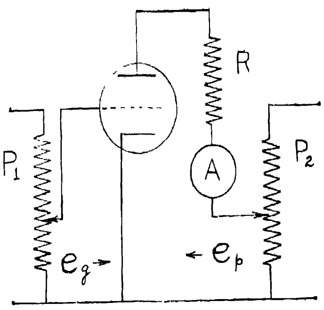

Figure 2. A thyratron phasemeter.

It would appear from above that $E_g = E_p/\mu$ is a critical condition.

It is to be noted that if the voltage applied to the grid is leading in phase (θ leading) then equation 1 ceases to have any meaning and $\sin(\omega t+\phi)=0$, if both ωt and ϕ are equal to zero. Physically it is clear that as there cannot be any conduction during the negative half cycle of the plate voltage (i. e., ϕ cannot be negative), the discharge can only start at $\phi=0$, whatever be the value of θ. Therefore I has the same magnitude for almost all leading angles. This is a major defect of the instrument. It is also to be noted that no consideration of R has been taken in the above treatment.

3. Experimental

The phasemeter is shown in figure 2. It has two potentiometers P_1 and P_2 in the grid and the plate circuit respectively, to control the relative values of the plate and grid voltages. In the preliminary test a gastube 885 was used with approximately 110 volts at the plate and 22 volts on the grid. With E_g just smaller than E_p/μ, θ (lagging) could be measured quite elegantly from 10° to about 180°. The range could be probably extended byond 180° as the equation 3 predicts, but this could not be verified as a proper phase-shifter was not available. Within the range mentioned the I-θ relation follows closely the graph II in figure 1, which is the graph for the equation 3. Although only power-frequency was tried with, it is obvious that the frequency range can be extended from below the power frequency to about 10 kc/s for Hg. vapour tubes and to 50 kc/s for light-gas tubes, the maximum frequency being limited by the recombination period of the gas ions after the voltage fall.

4. Conclusion

The author has investigated the possibility of using a thyratron as a phasemeter. The preliminary test justifies the attempt. The instrument is however not perfect and there is a lot of scope for improvement and modification. Certain modifications are being contemplated.

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